STAFF SUMMARY SHEET

	TO	ACTION	SIGNATURE (*Surname*), GRADE AND DATE		TO	ACTION	SIGNATURE (*Surname*), GRADE AND DATE
1	DFM	sig	Armacost, Col, 13 Jan 12	6			
2	DFER	approve	Burt A Rahn Col 19 Jan 2012	7			
3	DFM	action	(Author /Originator)	8			
4				9			
5				10			

SURNAME OF ACTION OFFICER AND GRADE	SYMBOL	PHONE	TYPIST'S INITIALS	SUSPENSE DATE
Pettit, Lt Col	DFM	333-2731	tjp	20120131

SUBJECT	DATE
Clearance for Material for Public Release USAFA-DF-PA-15	20120113

SUMMARY

1. PURPOSE. To provide security and policy review on the document at Tab 1 prior to release to the public.

2. BACKGROUND.
Authors: Timothy J. Pettit, Joseph Fiksel, and Keely L. Croxton (co-authors at The Ohio State University)

Title: Ensuring Supply Chain Resilience: Development and Implementation of an Assessment Tool

Circle one: Abstract Tech Report X Journal Article Speech Paper Presentation Poster

Thesis/Dissertation Book Other: ________________

Check all that apply (For Communications Purposes):

[X] CRADA (Cooperative Research and Development Agreement) exists (AFIT and OSU, expired July 2011)
[] Photo/ Video Opportunities [] STEM-outreach Related [] New Invention/ Discovery/ Patent

Description: Results of supply chain resiliese conducted at The Ohio State University and Air Force Institute of Technology.

Release Information: Submission for the Journal of Business Logistics, special issue on Supply Chain Risk

Previous Clearance information: None

Recommended Distribution Statement: Distribution A: approved for public release, distribution unlimited

3. DISCUSSION. Subject research was conducted under IRB approval from The Ohio State University. All subjects provided Informed Consent. No data on military policy, processes or technologies was gathered.

4. RECOMMENDATION. Recommend approval for Distribution A.

/// signed, TJP, 13 Jan 12//

TIMOTHY J. PETTIT, Lt COl, USAF, PhD
Assistant Professor, DFM

Ensuring Supply Chain Resilience: Development and Implementation of an Assessment Tool

Timothy J. Pettit[1], Joseph Fiksel[2], and Keely L. Croxton[2]

[1] U.S. Air Force Academy
[2] The Ohio State University

In today's tightly connected global economy, traditional management practices that rely on "steady-state" conditions are challenged by chaotic external pressures and turbulent change. Just in the last few years the world has experienced a string of catastrophic events, including a global economic meltdown, a volcanic eruption in Iceland, an oil spill in the Gulf of Mexico, a disastrous tsunami and power blackout in Japan, and political upheavals in Africa and the Middle East. Managing the risk of an uncertain future is a challenge that requires *resilience* – the ability to survive, adapt and grow in the face of turbulent change. This research develops a measurement tool titled the Supply Chain Resilience Assessment and Management (SCRAM™). Data gathered from seven global manufacturing firms is used to validate SCRAM™ using qualitative methodology with 1,369 empirical items from focus groups reviewing 14 recent disruptions. Critical linkages are uncovered between the inherent vulnerability factors and controllable capability factors. Through mixed-method triangulation, this research identified 311 specific linkages that can be used to guide a resilience improvement process. Pilot testing suggests a significant correlation between increased resilience and improved supply chain performance, with follow-on targeted modeling producing 500% Return on Modeling Effort.

Keywords: Resilience, Disruptions, Risk management, Supply chain management, Vulnerabilities

The views expressed in this article are those of the authors and do not necessarily reflect the official policy or position of the Air Force, the Department of Defense, or the U.S. Government.

INTRODUCTION

Global supply chains are growing in both length and complexity (Blackhurst et al. 2005) and the turbulence that they experience is increasing. In fact, a worldwide survey of international businesses reported that 85% of firms experienced at least one major disruption in the previous year (Business Continuity Institute 2011). Business leaders need a method to manage change in their complex supply chains. For example, the March 11, 2011, earthquake and tsunami that occurred in Japan and the subsequent nuclear crisis caused physical damage estimated from $195 billion to $305 billion" (Nato et al. 2011). The physical devastation and loss of 20% of the nation's electrical grid due to nuclear power shut-downs caused Toyota production to drop by 40,000 vehicles, costing $72 million in profits daily (Kachi and Takahashi 2011). Stock prices for Japanese auto manufacturers declined up to 9.5% within the first few days, and during the following month Toyota stock lost over 17% of its value and overall auto sales in Japan fell to a 34-year low (Takahashi 2011). The immediate and lingering effects of this natural disaster, and the subsequent supply chain disruptions, have spurred renewed concerns about supply chain resilience; however, "the development of practical methods to implement resilience in an engineering context is still in an incipient stage" (Park, Seager and Rao 2011). Therefore, this research develops a tool that will help supply chain leaders to assess their current level of resilience and to guide purposeful change so that their supply chain can survive, adapt and grow in the face of a complex and unpredictable future.

Complexity is difficult to manage (Mason 2006) and systems with a large number of elements can be vulnerable to non-linear interactions, with small perturbations causing severe impacts. Knowing the history of a dynamic, complex system does not necessarily lead to foresight because the system behavior and the external conditions constantly change (Snowden

and Boone 2007). Compounding the complexity of today's supply chains is the severe impact of disruptions. Hendricks and Singhal (2005) found that over the period from one year before through two years after a disruption is announced, stock prices declined nearly 40%.

Conventional risk-management approaches designed to deal with traditional incidents such as floods or management crises, are not always effective when a company is confronted with unexpected disruptions. The predominant approach to enterprise risk management requires risk identification and quantification, which are not always possible in the absence of empirical data. Moreover, strategies to deal with change need to be purposely aligned with a company's earning drivers (Ahlquist et al. 2003), and firms need to balance revenue streams with preparation and recovery costs, short-term customer service and long-term supply chain value in terms of return on assets (Slone, Mentzer and Dittmann 2007). The Council on Competitiveness argues that "managing this rapidly changing risk landscape is an emerging competitive challenge" and meeting that challenge demands resilience (Council on Competitiveness 2007).

The Supply Chain Resilience Framework (Pettit, Fiksel and Croxton 2010) identifies the sources of change in seven categories of vulnerabilities: Turbulence, Deliberate threats, External pressures, Resource limits, Sensitivity, Connectivity and Supplier/Customer disruptions. These vulnerabilities must be counter-balanced with managerial controls that create supply chain capabilities: Flexibility in sourcing, Flexibility in order fulfillment, Capacity, Efficiency, Visibility, Adaptability, Anticipation, Recovery, Dispersion, Collaboration, Organization, Market position, Security and Financial strength. The balance between vulnerabilities and capabilities must be measured in order to assess the current level of resilience.

This research follows the conceptual foundations of Pettit et al. (2010) to create a measurement instrument that helps managers implement the Supply Chain Resilience

Framework, thus providing direction for a supply chain to improve its resilience. This paper begins with a literature review, describes the methodology used to create and validate the assessment, presents results and recommendations from initial application of the instrument with seven global manufacturing supply chains, reports empirically derived linkages between vulnerabilities and capabilities, and concludes with a summary of a pilot implementation within a global manufacturing supply chain.

LITERATURE REVIEW

Supply chain resilience draws from the foundations of many disciplines, including ecology (Folke et al. 2002, 2004; Perrings 2006), psychology (Bonanno 2004; Gorman et al. 2005), sociology (Adger 2000), risk management (Starr, Newfrock and Delurey 2003) and network theory (Callaway et al. 2000). Following a series of major disruptive events in global economies, several in-depth studies were conducted to better understand how supply chains can more effectively adapt to change (Cranfield University 2002, 2003; Sheffi 2005). As the term resilience entered the business vocabulary, researchers investigated enterprise attributes that contribute to supply chain disruptions and attributes that assist enterprises in preventing and coping with those disruptions (Hamel and Valikangas 2003; Rice and Caniato 2003; Christopher and Peck 2004; Kleindorfer and Saad 2005; Tang 2006b, Blackhurst et al. 2011). Flynn (2008) defines resilience with the "four Rs" – robustness, resourcefulness, recovery and review. Rice and Caniato (2003) and Sheffi (2005, 2008) focus resilience on redundancy and flexibility, recommending leaders to develop a "flexibility DNA" through communications, distributed authority, passion for the mission, deferring to experience and conditioning for disruptions.

Although these viewpoints vary, they all differentiate resilience from traditional risk management (COSO 2004; Tang 2006a; Manuj and Mentzer 2008). The concept of resilience,

unlike conventional risk analysis, utilizes strategies that do not require exact quantification, complete enumeration of possibilities, or assumptions of a representative future (Pettit et al. 2010). Strategic resilience imperatives call for supply chains to be less brittle and more adaptive to change through: 1) supply chain design, 2) focus on business process management to enhance capabilities across the supply chain, 3) visibility to demand and supply throughout the supply chain, 4) supplier and customer relationship management and 5) infusing a culture of resilience (Wisdomnet 2006).

With operational risk rated as the most important risk that executives face, increasing economic value through better risk-based decision making is often viewed as a top imperative (Towers-Perrin 2006). Any organization that hopes to become resilient must address four challenges: the cognitive challenge, the strategic challenge, the political challenge and the ideological challenge (Hamel and Valikangas 2003). The breadth of these challenges underscores the necessity of an enterprise-wide view of the firm. Firms must develop a resilient supply chain in order to survive and prosper, and in addition they need to collaborate with resilient supply chain partners,

However, Pettit et al. (2010) identified a research gap in linking vulnerabilities and threats to the strategies to overcome them. Based on the foundations in life and social sciences, resilience was defined by Fiksel (2006) and adapted by the Council on Competitiveness (2007) as "the capacity for an enterprise to survive, adapt and grow in the face of turbulent change." Resilience was proposed to consist of two constructs: Vulnerabilities – *fundamental factors that make an enterprise susceptible to disruptions* and Capabilities – *attributes that enable an enterprise to anticipate and overcome disruptions* (Pettit et al. 2010). These constructs were refined to include 21 factors comprised of 111 sub-factors, see Tables 1 and 2. The authors

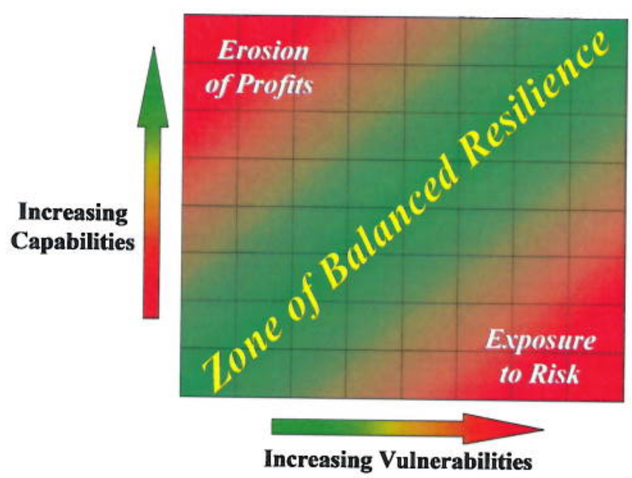
propose that assessment of these 21 factors can be used to evaluate a supply chain's current state of resilience, and therefore, based on a strategic review of the resilience fitness space, illustrated in Figure 1, recommendations for resilience improvements can be prioritized to meet corporate goals.

Until recently, the concept of supply chain vulnerability has been unexplored and its meaning was ambiguous (Svensson 2000). Svensson (2002) defines supply chain vulnerability as unexpected deviations from the norm and their negative consequences. A similar perspective is that vulnerability is a combination of the likelihood of an event and its potential severity (Sheffi 2005; Craighead et al. 2007). Both these definitions have foundations in traditional risk management techniques and are expanded by other authors (Chapman et al. 2002; Zsidisin 2003; Starr et al. 2003; Svensson 2004; Peck 2005; Elkington 2006). They treat vulnerabilities as essentially synonymous to risks. Taking a more fundamental view of vulnerabilities, we use the Pettit et al. (2010) definition of supply chain vulnerabilities as "fundamental factors that make an enterprise susceptible to disruptions" (Pettit et al. 2010). Thus, vulnerabilities are a precursor to risks, and a particular vulnerability (e.g., lack of backup power) can make a firm susceptible to a wide range of risks.

The responses, or solutions, to a vulnerability are varied and encompass the capabilities of the entire enterprise, as well as the conflicting or synergistic capabilities of the supply chain members (Hamel and Välikangas 2003; Hendricks et al. 2008; IOMA 2008; Blackhurst et al. 2011). Capabilities are defined as "attributes that enable an enterprise to anticipate and overcome disruptions" (Pettit et al. 2010). Earlier research defined 14 separate capability factors that can be managed to balance the inherent vulnerabilities in the supply chain, see Table 2. The goal for managers is to create a portfolio of capabilities that results in balanced resilience and is

hypothesized to improved supply chain performance. This research proposes that *supply chain resilience improves as capabilities increase and vulnerabilities decrease,* and asserts that increased resilience will allow a supply chain to better anticipate, react and adapt to the changing environment, thus improving performance. We therefore postulate that improved performance due to resilience will in the short-term result in improved business continuity, and in the long-term greater sustainability. This study set out to first develop a useful tool to measure the current state of a supply chain's resilience, examine the relationship between resilience improvements and supply chain performance, and then show how these results can be applied to improve resilience and therefore improve short- and long-term performance.

Figure 1: Resilience fitness space



Pettit, Fiksel and Croxton (2010)

Table 1: Vulnerability factors

Vulnerability Factor	Definition	Sub-Factors
Turbulence	Environment characterized by frequent changes in external factors beyond your control	Natural disasters, Geopolitical disruptions, Unpredictability of demand, Fluctuations in currencies and prices, Technology failures, Pandemic
Deliberate threats	Intentional attacks aimed at disrupting operations or causing human or financial harm	Theft, Terrorism/sabotage, Labor disputes, Espionage, Special interest groups, Product liability
External pressures	Influences, not specifically targeting the firm, that create business constraints or barriers	Competitive innovation, Social/Cultural change, Political/Regulatory change, Price pressures, Corporate responsibility, Environmental change
Resource limits	Constraints on output based on availability of the factors of production	Supplier, Production and Distribution capacity, Raw material and Utilities availability, Human resources
Sensitivity	Importance of carefully controlled conditions for product and process integrity	Complexity, Product purity, Restricted materials, Fragility, Reliability of equipment, Safety hazards, Visibility to stakeholders, Symbolic profile of brand, Concentration of capacity
Connectivity	Degree of interdependence and reliance on outside entities	Scale of network, Reliance upon information, Degree of outsourcing, Import and Export channels, Reliance upon specialty sources
Supplier/Customer disruptions	Susceptibility of suppliers and customers to external forces or disruptions	Supplier reliability, Customer disruptions

Pettit, Fiksel and Croxton (2010)

Table 2: Capability factors

Capability Factor	Definition	Sub-Factors
Flexibility in Sourcing	Ability to quickly change inputs or the mode of receiving inputs	Part commonality, Modular product design, Multiple uses, Supplier contract flexibility, Multiple sources
Flexibility in Order Fulfillment	Ability to quickly change outputs or the mode of delivering outputs	Alternate distribution channels, Risk pooling/sharing, Multi-sourcing, Delayed commitment/Production postponement, Inventory management, Re-routing of requirements
Capacity	Availability of assets to enable sustained production levels	Reserve capacity, Redundancy, Backup energy sources and communications
Efficiency	Capability to produce outputs with minimum resource requirements	Waste elimination, Labor productivity, Asset utilization, Product variability reduction, Failure prevention
Visibility	Knowledge of the status of operating assets and the environment	Business intelligence gathering, Information technology, Product, equipment and people visibility, Information exchange
Adaptability	Ability to modify operations in response to challenges or opportunities	Fast re-routing of requirements, Lead time reduction, Strategic gaming and simulation, Seizing advantage from disruptions, Alternative technology development, Learning from experience
Anticipation	Ability to discern potential future events or situations	Monitoring early warning signals, Forecasting, Deviation and near-miss analysis, Risk management, Business continuity/preparedness planning, Recognition of opportunities
Recovery	Ability to return to normal operational state rapidly	Crisis management, Resource mobilization, Communications strategy, Consequence mitigation
Dispersion	Broad distribution or decentralization of assets	Distributed decision-making, Distributed capacity and assets, Decentralization of key resources, Location-specific empowerment, Dispersion of markets
Collaboration	Ability to work effectively with other entities for mutual benefit	Collaborative forecasting, Customer management, Communications, Postponement of orders, Product life cycle management, Risk sharing with partners
Organization	Human resource structures, policies, skills and culture	Accountability, Creative problem solving, Cross-training, Substitute leadership/empowerment, Learning/benchmarking, Culture of caring
Market position	Status of a company or its products in specific markets	Product differentiation, Customer loyalty/retention Market share, Brand equity, Customer relationships, Customer communications
Security	Defense against deliberate intrusion or attack	Layered defenses, Access restrictions, Employee involvement, Collaboration with governments, Cyber-security, Personnel security
Financial strength	Capacity to absorb fluctuations in cash flow	Insurance, Portfolio diversification, Financial reserves and liquidity, Price margin

Pettit, Fiksel and Croxton (2010)

METHODOLOGY FOR DEVELOPING THE MEASUREMENT TOOL

In accordance with Grounded Theory development (Glaser and Strauss 1967), the categories developed in the Supply Chain Resilience Framework (Pettit et al. 2010) were derived through empirical evidence; however, additional evidence is necessary to validate these concepts. Using systems theory to view supply chains as open systems that are influenced by, and interact with, their environment (Katz and Kahn 1978), this study uses the concept of vulnerabilities as influences and capabilities as continuous interactions. A two-step process was selected to measure and then validate, using a case study methodology (Eisenhardt 1989; Yin 1994; Esper, Fugate and Davis-Sramek 2007; Blackhurst et al. 2011) with qualitative analysis (Miles and Hubermann 1984).

First, an assessment tool was created to measure each element of the Supply Chain Resilience Framework. Seven firms each selected one of their product-lines or product-families for evaluation. Second, to validate the assessment tool, a series of focus groups was conducted with each participating firm using a multiple case study methodology in order to evaluate several recent disruptions. The goal of these focus groups was not to promote consensus-building or decision making, but to gather a broad base of information on complex issues (Morgan 1996). In this way, a complete evaluation of the assessment tool and its ability to accurately measure the construct of resilience was accomplished. Therefore, this research combines seven assessments from a variety of heterogeneous firms followed by multiple disruption case studies at each firm in order to fully justify previous theory building (Eisenhardt and Graebner 2007).

THE ASSESSMENT TOOL, SCRAM™

Instrument Development

Based on the Supply Chain Resilience Framework (Pettit et al. 2010), a survey-based assessment tool – the Supply Chain Resilience Assessment and Management (SCRAM™) – was created to subjectively measure each factor and sub-factor. Due to the vast scope of supply chain resilience, employing multiple items per sub-factor was not practical in order to maintain a reasonable survey length (Dillman 2000). In order to determine internal priorities and compare results between heterogeneous companies, the survey concluded with questions rating the relative importance of the factors (Lambert 2006). Survey responses were designed in ordinal form using the 5-point Likert Scale "Agree/ Disagree." Considerable care was made to word each question and response in a parallel manner to assist participants in responding both quickly and accurately.

Instrument Refinement

Following a pre-test and refinement by four academics and five practitioners, a larger-scale pilot test was implemented at a global fashion retailer in a continued effort to refine the tool prior to implementation (n=15, response rate of 75%). As multiple measures were categorized to represent resilience factors, the refinement process checked for unidimensionality of factor measures that include multiple variables. Cronbach's alpha was used as an unbiased estimator of internal consistency of responses based on the average inter-item correlation (Cronbach 1951; Malhotra 1993). Well-developed scales will have a Cronbach's alpha of 0.7 or greater; however, others propose lesser values as acceptable in exploratory research (Hair et al. 1998; Loehlin 1998; Min and Mentzer 2004). Results were acceptable and all items retained, see Table 3.

Table Error! No text of specified style in document.: Internal Reliability of Factor Measures

	V1	V2	V3	V4	V5	V6	V7
Number of Items	6	6	6	6	9	5	2
Cronbach's Alpha (Pilot)	0.819	0.874	0.845	0.806	0.829	0.536	0.918
Sample size*	13	13	14	14	10	15	14
Cronbach's Alpha (Main Main)	0.651	0.756	0.746	0.730	0.704	0.745	0.756
Sample size*	138	134	142	105	102	130	142
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**
Number of Items	5	6	3	5	4	6	6
Cronbach's Alpha (Pilot)	0.617	0.613**	0.584	0.463	0.141	0.695	0.921
Sample size*	8	13	13	11	12	10	12
Cronbach's Alpha (Main Main)	0.288	0.677	0.515	0.701	0.813	0.708	0.803
Sample size*	75	90	96	108	123	91	99
	C8	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**
Number of Items	4	5	5	6	6	6	4
Cronbach's Alpha (Pilot)	0.572	0.438	0.394	0.565	0.920	0.796	0.572
Sample size*	15	15	10	15	14	7	15
Cronbach's Alpha (Main Main)	0.682	0.461	0.615	0.779	0.763	0.896	0.682
Sample size*	136	115	89	158	141	87	136

* Sample size due to listwise deletion of missing or "Don't Know" responses, of Pilot N=15, Main Sample N=170.

** Pilot study contained only 5 items for C2.

Sampling Methodology

Theoretical sampling was chosen to identify firms with supply chains that were compelling examples of the target population of global manufacturing firms while also providing the necessary research access (Yin 2003). Based on the enterprise view of supply chain resilience, each sponsor was requested to appoint "thought leaders" or "key informants" (Voss, Tsikriktsis and Mark 2002) from various functions to participate: research and development,

marketing, procurement, production, logistics, finance, sales, risk management, security, information technology and others as necessary. A total of 170 participants participated in the seven assessments, as shown in Figure 2. It should be noted that Company F elected to use a reduced team size, identifying only senior-level managers from each functional specialty to capture the complete enterprise view. Finally, to test for generalizability the sample was tested for variance in demand volatility to ensure a wide spread of market influences. Demand volatility was chosen as a primary component of turbulence, and as theorized by resilience, a supply chain facing higher levels of change must be more resilient to survive. Volatility spread is shown in Figure 3 as calculated by each firm's primary measure of demand for the products scoped for the assessment. In a comparison to the target population, the sample firms have average quarterly revenue volatility over the past 5 quarters of 0.13 (coefficient of variation), as compared to the 18 manufacturing firms in the Dow Jones Industrial Average with revenue volatility of 0.09. Thus, this limited sample represents a relatively wide range of volatility for generalizability with a combined average near market means. Each firm in the sample was well-established having operated from 25 to 128 years (averaging 76 years).

Table 4: Description of sample

Company A	Global retailer of personal care, beauty and apparel products
Company B	Regional division of a multinational consumer electronics corporation
Company C	State-wide medical transportation firm operating as a non-profit
Company D	Major division of a global chemical company
Company E	Global manufacturer of personal care items
Company F	Global manufacturing firm in the building materials industry
Company G	Division of a multinational chemical company

Figure 2: SCRAM™ participants

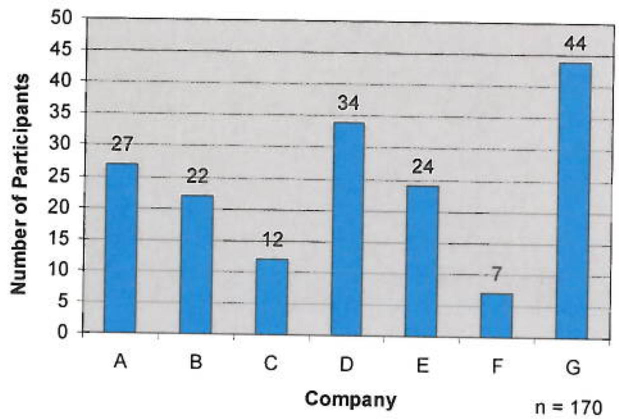
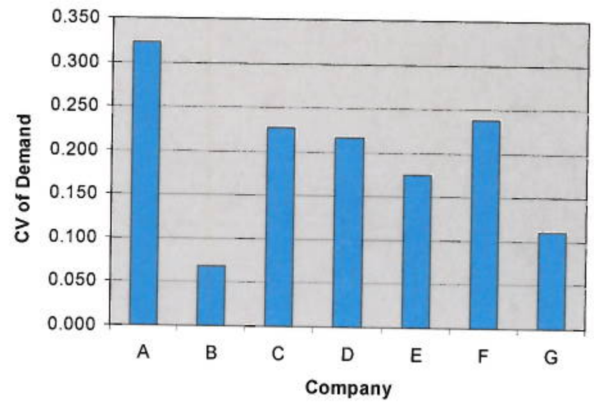


Figure 3: Demand volatility in sample



Data Collection

A secure, on-line survey was used to distribute the assessment in a user-friendly, cost-effective manner (Griffis, Goldsby and Cooper 2003). Format and design of the instrument used tenets of effective web-based surveys from Dillman (2000) (e.g. clear introductions, detailed instructions, parallel questions, consistent page layout, limited length and back paging). Participation in assessments was excellent due to the methodology of selecting a corporate sponsor to lead the project within each firm. Final response rates range between 76% and 100%, with an overall response rate of 82%. Techniques employed to increase response rates included preliminary messages, follow-up reminders, survey sponsorship, personalization of requests, cover letters, and assurance of anonymity and deadline dates (Kanuk and Berenson 1975; Lambert and Harrington 1990). Groves and Peytcheva (2008) list their first recommendation for reducing the risk associated with nonresponse bias is to achieve high response rates. All samples met or exceeded 76% response rate – higher than all 59 studies evaluated by Groves and Peytcheva (2008). Hence, the effect of any nonresponse bias, if it existed, would be minimal on the larger set of respondents.

Data recorded a minimal amount of blank entries, 1%, and a minor but expected amount of "Don't Know" responses, 10%. Allowing respondents to select "Don't Know" was critical in this assessment due to the breadth of the enterprise view of the Supply Chain Resilience Framework. Subjects also rated the relative level of importance of each factor on a similar 5-point Likert Scale for consistency, using end-points of "Minor Importance" and "Critical", with the central point as "Important." Average time to complete the assessment was 30.1 minutes.

Focus Groups

Disruptions can be classified as accidents, intentional actions or simply random events (Sheffi and Rice 2005), and a significant amount of insight on the cause of successful and unsuccessful reactions can be garnered from the organizational memory of recent, important events. "Through qualitative interviews you can understand experiences and reconstruct events in which you did not participate" (Rubin and Rubin 2005). Focus groups were guided by a semi-structured interview protocol to collect necessary data, while maintaining the highest level of reliability possible. This protocol uses probes, as applicable, to prompt the group for further explanation or more depth (Crabtree and Miller 1999). The protocol was essential for gathering a consistent set of data especially important with "heterogeneous groups, reflecting a maximum variation sample to effectively gather multiple perspectives on the topic under inquiry" (Patton 1990). And finally, Crabtree and Miller (1999) recommend designing the focus group protocol to generate discussion by subjects from multiple functions within the firm who may have different motivations, skills, experiences and outcomes; this was crucial in order to gain insight from the various perspectives required to assess Supply Chain Resilience.

Sample

Five of the seven firms participating in the SCRAM™ assessment continued with follow-on disruption analyses for qualitative validation. The minimum group size was two, avoiding a single biased response while encouraging more depth in responses (Goldman 1962; Morgan 1996). Selection criterion for topics was the type of disruption based on the failure mode. By studying various types of disruptions, each data set revealed new information in addition to many overlapping concepts. Despite the recognition that an infinite number of disruptive causes exist (Sheffi 2005), several authors have divided the spectrum of disruptions into categories (Rice and Caniato 2003; Hendricks and Singhal 2003; Kleindorfer and Saad 2005; Manuj and Mentzer 2008). This study therefore categorizes disruptions into the set of:

- **Supply-side disruptions:** *relating to the creation, delivery and availability of supplies when and where needed*
- **Production disruptions:** *the process of creation of products or services by the focal firm*
- **Demand-side disruptions:** *relating to distribution and sale of products to customers through to the end consumer, including additional manufacturing downstream of the focal firm*

By including multiple disruptions from each category, a more thorough data set will be gathered relative to the enterprise characteristics of the Supply Chain Resilience Framework for validation. Fifty-six participants from 14 focus groups were involved, as listed in Table 5.

Table 5: Disruption case studies

Company	Disruption Title	# of subjects	Type of Disruption	Number of Data Items Collected
A	ILWU Lockout 2002	6	Supply-side	55
	Product Launch Overestimation	1	Demand-side	53
B	Contract Manufacturer Delays for New Product Launch	2	Supply-side	85
	Warehouse Capacity Limitations to Meet End-of-Quarter Loads	9	Operations	158
	Instability in Government Regulations in Venezuela	2	Demand-side	131
	Alignment of Revenue Forecasts with Procurement Forecasts	3	Other	42
D	Container and Transport Availability to Asia	5	Supply-side	93
	Transition of Production to New Site	5	Operations	89
	Multiple Changes in Delivery Date for Extremely Large Order by Major Customer	3	Demand-side	87
E	Instability of Product Formulation from Supplier	3	Supply-side	125
	Major Demand Changes for Promotional Item	3	Demand-side	97
G	Single-Sources Supply Failure	5	Supply-side	103
	Product Shortage	4	Operations	83
	Outbound 3PL Provider Causes Delivery and Customs Delays	5	Demand-side	168

Instrument Validation and Reliability

"Validity is not a commodity that can be purchased with techniques" (Brinberg and McGrath 1985). However, the ideal state is to be pursued through research techniques designed into each stage of the process. Construct validity, ensuring operational measures are proper for the concepts being studied (Miles and Huberman 1984; Ellram 1996; Yin 2003), was controlled using multiple respondents from each of several functional areas in the firm and multiple levels of management to measure the overall level of resilience. Results were also presented to corporate leaders for final testing of construct validity. External validity, the extent to which the results accurately represent the phenomenon studied, thus establishing generalizability (Ellram 1996; Yin 2003), was designed into the study through a sample that includes multiple firms from

the spectrum of markets. Reliability, demonstrating that the operations of a study can be repeated with the same results (Yin 2003), was controlled through a pre-test and pilot test of the assessment tool and, for the case studies, evaluated using a hold-out sample. These post-focus group responses recorded 119 reliability items, yielding 95% of common information with the focus groups and only 5 new pieces of information. Results of blind-coding by two separate researchers found 83% of vulnerabilities were like-coded while only 42% of capabilities were similar; initial blind-coding reliability of 60% is considered good (Miles and Huberman 1984). Therefore, a consensus session was conducted and most issues were resolved with multiple codings for each line item, a sign that reinforces the complexity and inter-correlation of the resilience factors. These consensus results were used for analysis.

Validation Results

Data from these 14 disruption focus groups was used to validate the Supply Chain Resilience Assessment and Management tool, SCRAM™. See Table 6 for summary statistics of focus group data.

Table 6: Validation data summary

	Firms	Focus Groups	Subjects	Number of Data Line items	# of Positive Coded Items	# of Negative Coded Items
Total	5	14	56	1,369	805	340
Average per Focus Group			4.0	97.8	57.5	24.3
				Vulnerabilities	459	11
				Capabilities	315	315

The chosen methodology was very successful in exploring these complex issues through a combination of detailed and open-ended questioning. As the focus groups were investigating actual disruptions, very few low-vulnerability issues were discussed. On the contrary, a good variety of capabilities were coded implying that the focus groups conveyed their supply chain's strengths as well as their weaknesses. Qualitative evaluation of the assessment tool's construct validity was evaluated using these interpretive codes. The factor scores from the SCRAM™ assessment were used for comparison. Using the number of firms that validated each capability score, a 92.9% validation rate was computed. Disruption focus groups reported very few low vulnerabilities, so a similar computation was not possible. Therefore, each vulnerability category was reviewed for each focus group in relation to their SCRAM™ results. In all 14 cases, the reports from these recent disruptions validated the subjective survey data.

RESULTS AND ANALYSIS

Assessment Results

The exploratory methodology dictated review and analysis of each assessment individually and later as a whole. Following the administration of each SCRAM™ instrument, data and preliminary recommendations were presented in an open forum with the sponsor and key functional leaders from their firm. These discussions provided strong validation of the measurement abilities of the tool as well as conceptual linkages between the vulnerabilities and capabilities that can potentially be used to improve a supply chain's balanced resilience.

Despite literature being dominated by case studies of weather and supplier related disruptions (Svensson 2000; Christopher and Peck 2004; Sheffi 2005), these findings are consistent with reported supply chain risks that rate infrastructure and complexity as greater

threats (Elkington 2006; Craighead et al. 2007). Summary of vulnerability rankings are shown in Table 7.

Table 7: Vulnerability score rankings

Ranking	Variable	Vulnerability Factor	Average rank*
1	V3	External pressures	2.0
2	V6	Connectivity	2.1
3	V5	Sensitivity	2.9
4	V4	Resource limits	3.7
5	V1	Turbulence	4.7
6	V7	Supplier/Customer disruptions	5.9
7	V2	Deliberate threats	6.7

* Using firm ranking among the seven companies in the main sample (i.e. rank 1=highest vulnerability to 7=lower vulnerability).

Similarly, each team discussed their assessed capabilities in rank order, beginning with their strengths. Table 8 lists the overall capability rankings based on the average firm ranks.

Table 8: Capability score rankings

Ranking	Variable	Capability Factor	Average rank*
1	C12	Market position	2.6
2	C8	Recovery	3.6
3	C14	Financial strength	3.9
4	C13	Security	4.3
5	C11	Organization	4.9
6	C9	Dispersion	5.3
7	C4	Efficiency	5.9
8	C7	Anticipation	9.3
9	C5	Visibility	9.7
10	C1	Flexibility in sourcing	10.1
11	C6	Adaptability	10.4
12	C2	Flexibility in order fulfillment	11.0
13	C3	Capacity	11.6
14	C10	Collaboration	12.6

* Using firm ranking among the seven companies in the main sample (i.e. rank 1=strongest capability to 14=weakest capability).

A closing review of each assessment mapped the factors scores with their relative importance. Both vulnerabilities and capabilities are reviewed; one example of concern is a firm with capabilities of low score and high importance: weaknesses that should be prioritized for improvement (Figures 4 and 5).

Figure 4: Prioritization of vulnerabilities

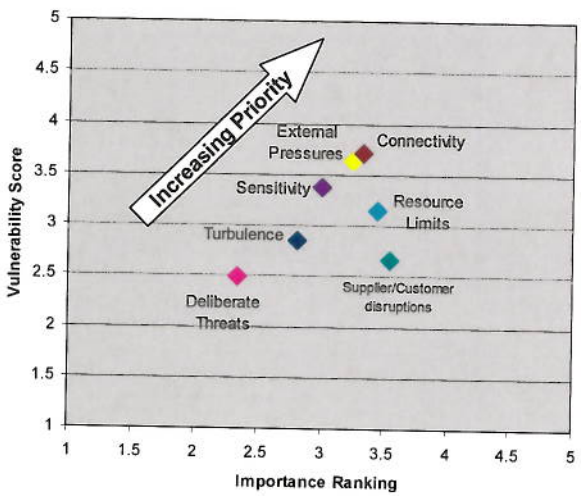
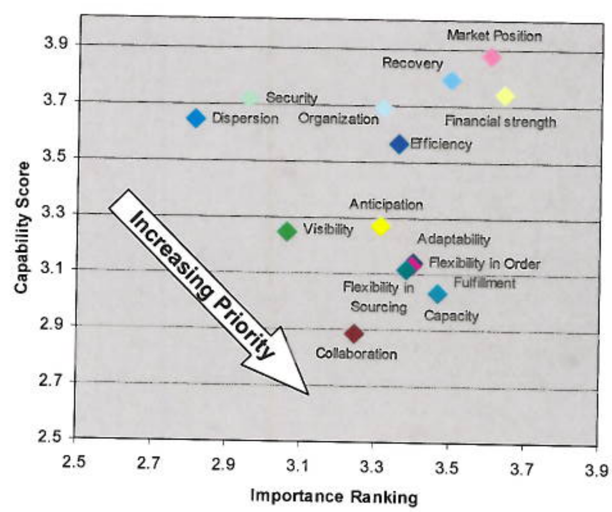


Figure 5: Prioritization of capabilities



Note: Reduced graph scale to improve readability.

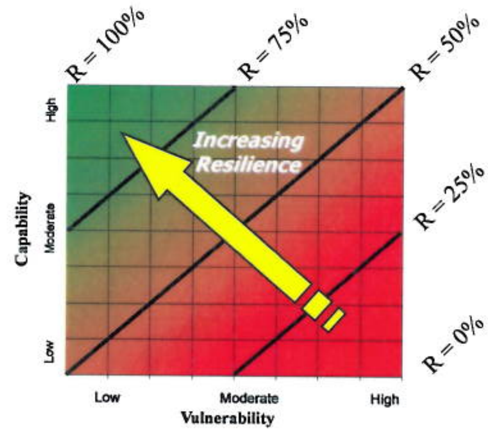
Influence of Resilience on Performance

The initial research proposition that "supply chain resilience improves as capabilities increase and vulnerabilities decrease" asserts that higher resilience will allow a supply chain to better anticipate, react and adapt to the changing environment, thus improving performance. We postulate that improved performance due to resilience will in the short-term result in lower performance volatility. For example, an extremely resilient supply chain will always meet customer demand at each tier through to the end consumer and will always be one-step ahead of

the competition. Data from the seven firms participating in this round of SCRAM™ assessments will be used to extract inferences on the potential relationship between resilience and performance.

Using the Supply Chain Resilience Framework, resilience can be computed using the two-dimensions of vulnerabilities and capabilities. The calculation of a resilience score, R, is based on a firm's average vulnerability score, V, and the average capability score, C, as given by $R = \frac{C - V + 4}{8}$ when utilizing the Likert Scale of 1-to-5 employed by the Supply Chain Resilience Assessment and Management (SCRAM™) tool. Construct scores can be computed by averaging the factor scores, assuming equal weights for each factor, in the manner of $V = \frac{\sum_{i=1}^{n_V} V_i}{n_V}, n_V = 7$, and $C = \frac{\sum_{j=1}^{n_C} C_j}{n_C}, n_C = 14$. Factor scores come directly from the assessment tool by averaging the associated sub-factors in a similar manner, again assuming equally weighted items, as $V_i = \frac{\sum_{k=1}^{n_{V_i}} V_{i,k}}{n_{V_i}}, i = 1 \rightarrow n_V$, where n_{Vi} varies with the number of items in the i^{th} vulnerability factor and $C_j = \frac{\sum_{k=1}^{n_{C_j}} C_{j,k}}{n_{C_j}}, j = 1 \rightarrow n_C$, where n_{Cj} varies according to the number of items in the j^{th} capability factor.

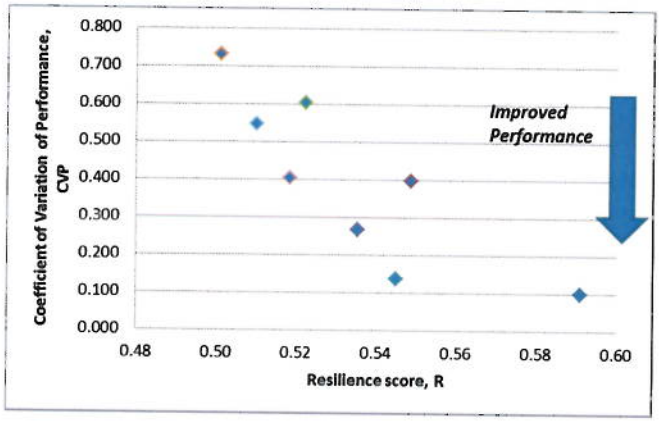
Figure 6: Resilience computation



Representing overall supply chain performance in relation to resilience, the volatility of supply chain performance measures was compared for each firm. However, in order to compare multiple metrics, each targeting a separate dimension of supply chain operations, the coefficient of variation, CV, is an appropriate measure of the volatility for cross-comparison and is defined as the ratio of the standard deviation to the mean. In this study, each participating firm provided between three to 12 performance measures, covering the period of assessment and one year prior to the assessment. Examples include availability, delivery lead-time, inventory position, order accuracy and customer complaints.

Exploratory data from this study is compared in terms of firm resilience and performance as shown in Figure 7 (note: one additional firm participated in a later study, n=8). Firms in this sample reporting higher resilience scores reported lower volatility of supply chain performance metrics. Through regression analysis, it was found that firms in the sample with lower resilience scores demonstrated higher volatility in performance metrics, thus inferring that there is a potential for performance gains due to improved resilience ($R^2 = 0.7004$).

Figure 7: Resilience inference on performance volatility



The Application of Mixed-Methods to Improve Resilience

Knowing your current state of resilience is only the first step – managers need reliable advice on how to improve their resilience in order to meet corporate strategies for survival and long-term growth. The Supply Chain Resilience Framework considers vulnerabilities as inherent characteristics of the supply chain environment and therefore fixed in the short-term, managers require identification of linkages between their vulnerabilities and the capabilities that they can directly control. For instance, if a manager identifies connectivity as a key vulnerability, what are the capabilities that he can choose to build to better protect the firm from this risk? And more importantly, as he looks across all the firm's vulnerabilities, what is the portfolio of capabilities that will best protect it from disruptions?

Based on the breadth of the Supply Chain Resilience Framework, identifying linkages is a very complex task. Editors of the *Journal of Operations Management* recently asserted that "it is our strong belief that multiple approaches are required in order to develop a holistic understanding of operations and supply chain management phenomena" (Boyer and Swink 2008). When applicable methods are applied with a variety of data, the convergence of multiple

methods provides additional validation (Jick 1979). Research methods in business management can be categorized by the method of data acquisition: theoretical, survey-based, case study-based and experimental. A recent surge in mixed-methods research has proven the applicability of these types of triangulation techniques, with 53% of articles reviewed from the year 2004 using mixed-methods (Frankel, Naslund and Bolumole 2005). Therefore, this phase of the exploratory research combines theoretical perspectives, quantitative methods and qualitative interpretation of empirical data to triangulate theoretical, survey-based, and case study-based data to develop confidence in the resulting resilience linkages.

Method A: Theoretical Linkages

During the first phase of this research, extant literature was consolidated and combined with insightful anecdotal evidence from practitioners building the researchers' baseline understanding of the concepts involved, which is necessary for theory construction (Yin 2003). Following eight on-site focus groups to categorize the 21 factors and 111 sub-factors of the Supply Chain Resilience Framework and discussing the results of seven Supply Chain Resilience Assessment and Management (SCRAM™) surveys with each firm's leadership, potential linkages were theorized by the research team. This concept is validated by a recent investigation of published logistics research, which concluded that significant contributions can be made "by the researcher spending time in organizations and observing and/or communicating with professionals performing logistics in action" (Frankel et al. 2005). This initial set of potential linkages is clearly biased by the researchers' knowledge, experience and deductive reasoning. Therefore, triangulation with empirical data searches for the confluence of conclusions will determine more stringent results.

Method B: Correlation of Survey Responses

Survey data was then gathered as a low-cost, non-invasive method for gathering expert perceptions on complex issues that may not be readily identified by objective measures. The use of multiple respondents from critical functional areas within the firm reduces individual bias while efficiently encompassing the breadth of issues relating to supply chain resilience. Statistically significant correlations between vulnerability scores and capabilities scores are of interest. From an exploratory perspective, this study does not attempt to define or predict the relationships or the direction of the relationships. For example, firms in the sample may employ well balanced resilience in a particular area by design and therefore these vulnerabilities will be positively correlated: low vulnerabilities matched with low capabilities, high vulnerabilities with high capabilities. It is noted that the absence of a significant correlation does not by itself negate the possibility of a linkage existing, only that the firms in the limited sample did not assess the relationship similarly. In addition, testing of these specific associations must be left for further studies incorporating performance measures directly associated with each linkage; however, through the use of moderately stringent confidence intervals (α=0.10) and the triangulation methodology employed, results will distill in the confluence of theory and empirical evidence.

Method C: Pattern Matching of Focus Group Responses

Focus groups are an excellent source of qualitative data when exploring complex issues (Morgan 1996). Case or field-based studies provide a qualitative approach to studying a phenomena in-depth, particularly poorly understood or emerging phenomena. Primarily used as a theory-building approach, case studies have been effectively employed in a large variety of situations and are excellent guides for conducting research in both the broader business environment (Eisenhardt 1989; Yin 2003) and the operations and supply chain management

literature (McCutcheon and Meredith 1993; Meredith 1998; Craighead and Meredith 2008; Blackhurst et al. 2011). Benefits of case studies include the ability to examine a topic in great depth, allowing a thorough examination of numerous factors and nuances. Limitations of case studies include cost and time, inability to generalize and prescribe, and potential for bias in the perceptions of the researchers (Boyer and Swink 2008). Recent case study research proves that qualitative methodologies can be as useful and as rigorous as other research methods, and if triangulated with quantitative methods, leads to improved theory development (Frankel et al. 2005). Using the 1,369 line items from the 14 focus groups discussed previously, additional analyses were performed to uncover empirical correlations between vulnerabilities and capabilities.

As quantitative methods alone frequently do not capture the complex interactions of the business environment, organizational issues and societal culture (Kiessling and Harvey 2005), this study's comparison of theoretical data, survey data and case study data creates a mixed-methods approach to produce results with the required depth and breadth.

Identification of Critical Linkages

Triangulation of two or more methods can capture a more complete, holistic and contextual portrayal of the units under study (Jick 1979). Results of this triangulation are encouraging: at the factor level, this research identified 45 theoretical linkages, correlations of SCRAM™ data revealed 20 potential linkages ($\alpha = 0.10$) and focus group responses identified 70 linkages. Table 9 summarizes the comparisons between these potential linkages using two-way and three-way comparisons. For maximum validity, the confluence of all three methods is desirable; however, the absence of results from a single method does not negate a potential linkage. Therefore, balancing the desire to create a reliable list of potential linkages with the

exploratory goal of identifying the maximum possible linkages for managers to consider when developing or modifying their portfolio of capabilities, Table 10 lists the two-way and three-way triangulations by vulnerability factor.

Table 9: Summary of factor-level linkages by methodology

One-way Comparisons	Two-way Comparisons	Three-way Comparisons	Number of Linkages*, **
1) A or B or C			83
	1) A and B		9
	2) A and C		37
	3) B and C		15
	Two-way links		43
	Two-way links not three-way links		34
		1) A and B and C	9

A = Theoretical Linkages, B = Survey Correlations, C = Focus Group Connections
* Maximum possible linkages = 7 vulnerabilities x 14 capabilities = 98.
** $\alpha = 0.10$ for correlations.

Table 10: Vulnerability factor linkages

Vulnerability Factor	Linked Capability Factors
Turbulence (V1)	• Flexibility in Sourcing (C1) * • Flexibility in order fulfillment (C2) * • Capacity (C3) * • Visibility (C5) ** • Adaptability (C6) * • Anticipation (C7) * • Recovery (C8) * • Dispersion (C9) * • Collaboration (C10) **
Deliberate threats (V2)	• Adaptability (C6) * • Anticipation (C7) * • Recovery (C8) * • Security (C13) *
External pressures (V3)	• Adaptability (C6) *
Resource limits (V4)	• Flexibility in sourcing (C1) ** • Flexibility in order fulfillment (C2) * • Capacity (C3) ** • Efficiency (C4) * • Adaptability (C6) * • Anticipation (C7) * • Dispersion (C9) * • Market position (C12) * • Financial strength (C14) **
Sensitivity (V5)	• Efficiency (C4) * • Adaptability (C6) * • Dispersion (C9) *
Connectivity (V6)	• Flexibility in sourcing (C1) ** • Flexibility in order fulfillment (C2) * • Visibility (C5) ** • Adaptability (C6) * • Anticipation (C7) * • Collaboration (C10) * • Organization (C11) * • Market position (C12) * • Financial strength (C14) *
Supplier/Customer disruptions (V7)	• Flexibility in sourcing (C1) ** • Flexibility in order fulfillment (C2) ** • Visibility (C5) * • Recovery (C8) * • Dispersion (C9) * • Collaboration (C10) * • Market position (C12) * • Financial strength (C14) *

* Significant from a two-way comparison only (A-B, B-C and/or A-C).
** Three-way comparison results.

A similar process was performed at the sub-factor level, which is the appropriate level of direct managerial action. Sub-factor linkages by methodology are: 1) 590 theoretical linkages (20.8% of total 2,840 possible links), 2) 414 correlated links, and 3) 232 focus group linkages. Results of the sub-factor-level triangulation are summarized in Table 11, with detailed sub-factor linkages presented in Tables A1 through A7. Of the 40 vulnerability sub-factors, this mixed-methods process identified 311 unique linkages at the 2-way level, with 90% of the vulnerability sub-factors covered by at least one of the 71 capabilities. These exploratory results provide an excellent guide for firms who have completed the SCRAM™ assessment and are taking the next step toward improving their resilience.

Table 11: Summary of sub-factor-level linkages by methodology

One-way Comparisons	Two-way Comparisons	Three-way Comparisons	Number of Linkages*, **
1) A or B or C			1,021
	1) A and B		95
	2) A and C		232
	3) B and C		36
	Two-way links		311
	Two-way links not three-way links		275
		1) A and B and C	36

A = Theoretical Linkages, B = Survey Correlations, C = Focus Group Connections
* Maximum possible linkages = 40 vulnerabilities x 71 capabilities = 2,840.
** $\alpha = 0.10$ for correlations.

Improving Resilience

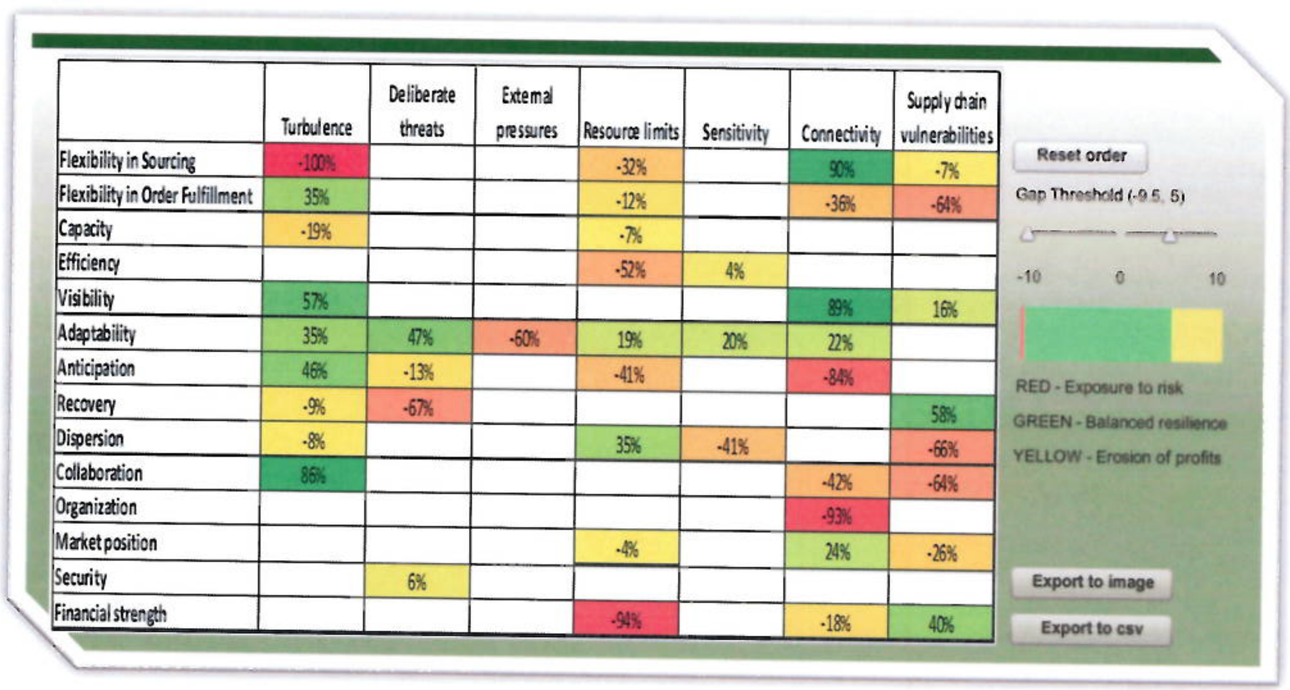
Creating a tabular format for depicting Resilience Gaps for each of these factor and sub-factor linkages provides corporate leaders with insight into potential improvement opportunities. Resilience Gaps are computed from percentage distance from the centerline of the Zone of Balanced Resilience, in the form of

$$R_{GAP_{i,j}} = \frac{C_i - V_j}{4}, \textit{for all i,j in which a linkage exist, where } C_i \textit{ and } V_j \textit{ range from 1-5}$$

Positive gaps represent higher capability than the associated vulnerability, potentially eroding profits; negative gaps have lower capability than the associated vulnerability, exposing the firm to potential risks. As can be seen in the example in Figure 8, managers can use this data to show where to focus their attention. This data suggests that the firm is vulnerable to turbulence, and while they lack flexibility in sourcing to deal with it, they have built-up other capabilities to protect themselves against this risk.

Pending further studies into the boundary conditions of the Zone of Balanced Resilience, it was very helpful to allow managers to adjust their own gap limits for presentation and discussion. In most cases conducted in this study, managers tuned the gap limit to a pseudo 80-20 rule; approximately 10% of linkages being above the upper limit, and another 10% below the lower limit. This allowed focus on the extreme issues for priority action.

Figure 8: Depiction of resilience gaps by linkages



	Turbulence	Deliberate threats	External pressures	Resource limits	Sensitivity	Connectivity	Supply chain vulnerabilities
Flexibility in Sourcing	-100%			-32%		90%	-7%
Flexibility in Order Fulfillment	35%			-12%		-36%	-64%
Capacity	-19%			-7%			
Efficiency				-52%	4%		
Visibility	57%					89%	16%
Adaptability	35%	47%	-60%	19%	20%	22%	
Anticipation	46%	-13%		-41%		-84%	
Recovery	-9%	-67%					58%
Dispersion	-8%			35%	-41%		-66%
Collaboration	86%					-42%	-64%
Organization						-93%	
Market position				-4%		24%	-26%
Security		6%					
Financial strength				-94%		-18%	40%

Notional data.

Simulation modeling: The next step

As a problem solving tool for stochastic systems such as supply chains, simulations can be very powerful. A model is only an abstraction of reality; however, modeling allows for exploration of key variables and processes without costly commitments or repercussions and allow for analysis of complex systems too intricate for mathematical equations or direct experimentation (Banks et al. 2005). Of course, there is a tradeoff between model accuracy and the confidence, but the high cost of data collection and the exponentially increasing complexity of vast supply chain models favor a very focused tack. Therefore, the SCRAM™ analysis provides the rapid, inexpensive overview with the necessary direction for a targeted modeling effort. In one such project, the Dow Chemical Company applied this process to their Glycol Ethers P-Series family of products, and was recognized as a Finalist in the Supply Chain Innovation Award competition (McIntyre and Hemmelgarn 2011). Here, the SCRAM™ analysis led to a scenario exploration of right-sizing fixed assets and working capital, which provided a potential $1.1 million savings for this business and represents a 500% Return On Modeling Effort.

RECOMMENDATIONS FOR FUTURE RESEARCH

Several concerns were noted during this research and are presented here for future research. Larger scale implementation is necessary to validate the measurement scales, identifying critical zones and clusters. Also, future research may determine multiple measures at the sub-factor level, with the addition of objective measurements where appropriate. As these measures become more specialized, it may be necessary to create industry-specific items or even firm- or product-level assessment items. Assessment of Supplier/Customer disruptions may need

to be expanded or a methodology developed to implement the SCRAM™ tool at various tiers of the supply chain and integrate the results.

As the current scope of the Supply Chain Resilience Framework is based on resilience in the context of ensuring operational business continuity, a broader extension to include strategic sustainability can yield further insights. Managers in a strategic role are concerned with longer planning horizons with focus on both financial and social responsibilities.

Now that we can measure the current state of supply chain resilience, the next step is to refine the process of integrating the vision of resilience into organizations. It is also recommended to apply this assessment tool with both upstream and downstream partners in order to get a full view of the supply chain's resilience. Additionally, evolving capabilities such as sustainability should be included in more depth. The final barrier to resilience is ideological (Hamel and Valikangas 2003). Educating corporate leaders on the concept of resilience and providing tool such as the Supply Chain Resilience Assessment and Management, SCRAM™, will greatly enhance current risk management strategies to allow supply chains to survive, adapt and grow in the face of turbulent change.

CONCLUSIONS

The Supply Chain Resilience Assessment and Management (SCRAM™) tool proved to be a valid method of evaluating the current level of resilience of a firm. Presentation of results to corporate sponsors and their functional leaders provided excellent feedback as to the breadth of the Supply Chain Resilience Framework and the ability of the SCRAM™ tool to accurately measure the sources of change facing the firm as well as the firm's strengths and weaknesses. By analyzing results from seven firms with global manufacturing supply chains, it was found that External pressures and Connectivity are the highest vulnerabilities facing this diverse group

of companies. Although the firms in the sample reported relatively low threats from Supplier/Customer disruptions, this data validated previous studies by placing the highest importance on these issues impacting the supply chain.

Firms in this study reported capability strengths in the areas of Market position, Recovery and Financial strengths. However, consistent reports of low Collaboration, lack of excess Capacity and minimal Flexibility raised serious concerns to the corporate sponsors. When highly rated vulnerabilities were discussed in relation to linked capabilities, sponsors were compelled to action to improve their resilience within the fitness space to best match the Zone of Balanced Resilience.

Managing change is essential. In the corporate environment not being prepared for change and not designing and managing a supply chain that can react and adapt quickly can be very costly. "After adjusting for industry and economy effects, the average effect of disruptions is a 107% drop in operating income, 7% lower sales growth and 11% growth in cost" (Hendricks and Singhal 2005). This exploratory study used supply chain performance measures to provide an initial assessment to infer that there is a positive relationship between increased resilience and improved operating performance for the firms within this study. Results show a potential for a 26% improvement in performance volatility for a single percentage point increase in resilience score as assessed by the Supply Chain Resilience Assessment and Management (SCRAM™) tool for these seven companies. Larger studies will be needed to confirm these results, but the evidence from business literature, industry leaders and academics also confirms the necessity for resilience (FM Global 2007; Council on Competitiveness 2007; Sheffi 2008).

Traditional risk management is a successful tool when events can be clearly identified, probability of occurrence and potential severity can be accurately quantified and future events

occur in similar fashion to the past. In an increasingly complex society, these assumptions are becoming less and less applicable. However, the concept of resilience for supply chain operations has proven potential to improve overall operational performance, both in times of dramatic change and times of relative stability (Flynn 2008). This research recommends a process of first identifying the supply chain structure through mapping, followed by the SCRAM survey that provides direction for detailed modeling. In such a way, a firm can quickly assess their current state of supply chain resilience and evolve their resilience with strategy selections that are cost effective.

Supply chain managers are striving to create resilient supply chains. Just like legendary leaders throughout history, Estep (2005) concludes with a metaphor, originally popularized by President Kennedy (1959), which focuses the concept of resilience on avoiding the negative ramifications of disruptions with the positive prospect of seizing advantage from change:

> Peak performers use the Chinese symbol for *crisis* as the sign of resiliency. This symbol is made up two parts: the character for "*danger*" and the character for "*opportunity*," suggesting that opportunities often hide in crises. *(emphasis added)*

Although others highlight that the second character of the word for crisis (wei-ji) is more accurately translated as "an incipient moment" or "crucial point when something begins or changes" (Mair 2008), this meaning can still be appropriately applied as the *danger* of change is now, and the understanding of supply chain resilience can be the *crucial turning point*. Therefore, with the application of supply chain resilience management, supply chain leaders can now direct their supply chains toward peak performance.

REFERENCES

Adger W. 2000. "Social and ecological resilience: Are they related?", *Progress in Human* Geograph 24(3):347–364.

Ahlquist G, Irwin G, Knott D and Allen K. 2003. "Enterprise resilience," *Best's Review* 104(3):88.

Banks, J, Carson J, Nelson B, and Nicol D. 2005. Discrete-Event System Simulation. 4th ed. Upper Saddle River, New Jersey: Prentice-Hall, Inc.

Blackhurst J, Craighead C, Elkins C and Handfield R. 2005. "An Empirically Derived Agenda of Critical Research Issues for Managing Supply-Chain Disruptions," *International Journal of Production Research* 43(19):4067-4081.

Blackhurst J, Dunn J and Craighead C. 2011. "An Empirically Derived Framework of Global Supply Resiliency," *Journal of Business Logistics* 32(4):374-391.

Bonanno G. 2004. "Loss, trauma and human resilience: Have we underestimated the human capacity to thrive after extremely aversive events?" *American Psychologist* 59(1):20-28.

Boyer K and Swink M. 2008. "Empirical elephants: Why multiple methods are essential to quality research in operations and supply chain management," Editorial, *Journal of Operations Management* 26(2008):337-348.

Brinberg D and McGrath J. 1985. *Validity and the research process*, Beverly Hills, CA: Sage Publications.

Business Continuity Institute. 2011. "Supply chain resilience 2011," 3rd Annual Survey, November 2011, http://www.bcipartnership.com/supplychainform.html (December 8, 2011).

Callaway D, Newman M, Strogatz S and Watts D. 2000. "Network robustness and fragility: Percolation on random graphs," *Physical Review Letters* 85(25):5468–5471.

Chapman P, Christopher M, Jüttner U, Peck H and Wilding R. 2002. "Identifying and managing supply-chain vulnerability," *Logistics and Transport Focus* 4(4):59-64.

Christopher M and Peck H. 2004. "Building the resilient supply chain," *International Journal of Logistics Management* 15(2):1-13.

Committee of Sponsoring Organizations (COSO) of the Treadway Commission. 2004. *Enterprise risk management: Integrated framework*, www.coso.org/Publications/ERM/COSO_ERM_ExecutiveSummary.pdf (July 25, 2006).

Council on Competitiveness. 2007. "The resilient economy: Integrating competitiveness and security," www.compete.org, (June 20, 2007).

Crabtree B and Miller W. 1999. *Doing qualitative research* 2nd ed. Thousand Oaks, CA: Sage Publications, Inc.

Craighead C and Meredith J. 2008. "Operations management research: Evolution and alternative future paths," *International Journal of Operations & Production Management* 28(8):710-726.

Craighead C, , Blackhurst J, Rungtusanatham M and Handfield R. 2007. "The severity of supply chain disruptions: Design characteristics and mitigation capabilities," *Decision Sciences* 38(1):131-156.

Cranfield University. 2002. *Supply chain vulnerability: Executive report*, School of Business, Cranfield University.

Cranfield University. 2003. *Creating resilient supply chain: A practical guide*, Centre for Logistics and Supply Chain Management, School of Business, Cranfield University.

Cronbach L. 1951. "Coefficient alpha and the internal structure of tests," *Psychometrika* 16(3):297-334.

Dillman D. 2000. *Mail and Internet surveys: The tailored design method*, New York: Wiley.

Eisenhardt K. 1989. "Building theories from case study research," *Academy of Management Review* 14(4):532-550.

Eisenhardt K and Graebner M. 2007. "Theory building from cases: Opportunities and challenges," *Academy of Management Journal* 50(1):25-32.

Elkington M. 2006. "Managing risk in global supply chain," *Strategic Risk*, November 2006:26-27

Ellram L. 1996. "The use of the case study method in logistics research," *Journal of Business Logistics* 17(2):93-138.

Esper T, Fugate B, and Davis-Sramek B. 2007. "Logistics learning capability: Sustaining the competitive advantage gained through logistics leverage," *Journal of Business Logistics*, 28(2):57-81.

Estep T. 2005. "In search of the secrets to peak performers," *T+D*, American Society for Training and Development, February 2005:78-80.

Fiksel J. 2006. "Sustainability and resilience: Toward a systems approach," *Sustainability: Science, Practice & Policy* 2(2):1-8.

Flynn S. 2008. "Building a resilient nation: Enhancing security, ensuring a strong economy," Keynote address, Reform Institute, New York, NY, March 27, 2008.

FM Global. 2007. "Managing business risk through 2009 and beyond," www.protectingvalue.com (April 10, 2008).

Folke C, Carpenter S, Walker B, Scheffer M, Elmquist T, Gunderson L, et al. 2004. "Regime shifts, resilience and biodiversity in ecosystem management," *Annual Review of Ecology, Evolution, & Systematics* 35(1):557-581.

Folke C, Carpenter S, Elmquist T, Gunderson L, Holling C and Walker B. 2002. "Resilience and sustainable development: Building adaptive capacity in a world of transformations," *Ambio* 31(5):437–440.

Frankel R, Naslund D and Bolumole Y. 2005. "The 'white space' of logistics research: A look at the role of methods usage," *Journal of Business Logistics* 26(2):185-208.

Glaser B and Strauss A. 1967. The discovery of grounded theory: Strategies for qualitative research, Chicago: Aldine Publishing.

Gorman C, Dale S, Grossman W, Klarreich K, McDowell J and Whitaker L. 2005. "The importance of resilience," *Time Canada* 165(3):76-79.

Griffis S, Goldsby T and Cooper M. 2003. "Web based and mail surveys: A comparison of response, data and *cost,*" *Journal of Business Logistics* 24(2):237-258.

Groves R and Peytcheva E. 2008. "The impact of nonresponse rates on nonresponse bias," *Public Opinion Quarterly* 72(2):167-189.

Hair J, Anderson R, Tatham R and Black W. 1998. *Multivariate data analysis* 5th ed., Upper Saddle River, NJ: Prentice Hall.

Hamel G and Välikangas L. 2003. "The quest for resilience," *Harvard Business Review* 81(9):52-63.

Hendricks K, Singhal V and Zhang R. 2008. "The Effect of Operational Slack, Diversification, and Vertical Relatedness on the Stock Market Reaction on Supply Chain Disruptions," *Journal of Operations Management* 27(3):233-246.

Hendricks K and Singhal V. 2005. "Supply-chain disruptions: Torpedo shareholder value and profitability," *Metal Producing & Processing* 43(6):36-35.

Institute of Management and Administration (IOMA). 2008. "Disaster Preparedness 2008: The Guide to Building Business Resilience," www.ioma.com/issues/SPCRPT/1614902-1.html (August 21, 2008).

Jick T. 1979. "Mixing qualitative and quantitative methods: Triangulation in action," *Administrative Science Quarterly* 24(4):602-611.

Kachi H. and Takahashi Y. 2011. "Plant Closures Imperil Global Supplies," *Wall Street Journal Online*, www.wstonline.com, March 14, 2011 (December 8, 2011).

Kanuk L and Berenson C. 1975. "Mail surveys and response rates: A literature review," *Journal of Marketing Research* 12(4):440-453.

Katz D and Kahn R. 1978. *The Social Psychology of Organizations*, 2nd ed. New York: John Wiley.

Kennedy J. 1959. Remarks at the Convocation of the United Negro College Fund, Indianapolis, Indiana, April 12, 1959, www.jfklibrary.org (September 4, 2008).

Kiessling T and Harvey M. 2005. "Strategic global human resource management research in the twenty-first century: An endorsement of the mixed-method research methodology," *International Journal of Human Resource Management* 16(1):22-45.

Kleindorfer P and Saad G. 2005. "Managing disruption risks in supply chains," *Production & Operations Management* 14(1):53-68.

Lambert D. 2006. *Supply chain management: Processes, partnerships, performance* 2nd ed., Sarasota, FL: Supply Chain Institute.

Lambert D and Harrington T. 1990. "Measuring nonresponse bias in customer service mail surveys," *Journal of Business Logistics* 11(2):5-25.

Loehlin J. 1998. *Latent variables models: An introduction to factor, path and structural analysis* 3rd ed. Mahwah, NJ: Lawrence Erlbaum Associates.

Mair V. 2008. "Crises ≠ Danger + Opportunity: How a misunderstanding about Chinese characters has led many astray," Essay, Department of Chinese Language and Literature, University of Pennsylvania, www.pinyin.info/chinese/crisis.html (September 4, 2008).

Malhotra N. 1993. *Marketing research: An applied orientation,* Englewood Cliffs, NJ: Prentice Hall.

Manuj I and Mentzer J. 2008. "Global supply chain risk management strategies," *International Journal of Physical Distribution & Logistics Management* 38(3):192-223.

Mason R. 2006. "Coping with complexity and turbulence - an entrepreneurial solution," *Journal of Enterprising Culture* 14(4):241-266.

McCutcheon D and Meredith J. 1993. "Conducting case study research in operations management," *Journal of Operations Management* 11(3):239-256.

McIntyre J and Hemmelgarn S. 2011. "How one business made its supply chain more resilient," Presentation for the 2011 Supply Chain Innovation Award, Annual Global Conference of the Council of Supply Chain Management Professionals (CSCMP), October 4, 2011, Philadelphia, PA.

Meredith J. 1998. "Building operations management theory through case and field research," *Journal of Operations Management* 16(4):441-454.

Miles M and Huberman A. 1984. *Qualitative data analysis: A sourcebook of new methods*, Beverly Hills, CA: Sage Publications.

Min S and Mentzer J. 2004. "Developing and measuring supply chain management concepts," *Journal of Business Logistics* 25(1):63-99.

Morgan D. 1996. "Focus groups," *Annual Review of Sociology* 22(1):129-152.

Nanto D, Cooper W, Donnelly J and Johnson R. 2011. "Japan's 2011 Earthquake and Tsunami: Economic Effects and Implications for the United States," Congressional Research Service, April 20, 2011, www.crs.gov (December 8, 2011).

Park J, Seager T and Rao P. 2011. "Lessons in risk- versus resilience-based design and management," *Integrated Environmental Assessment and Management* 7(3):396–399.

Patton M. 1990. *Qualitative evaluation and research methods*, Newbury Park, CA: Sage Publications.

Peck H. 2005. "Drivers of supply chain vulnerability: An integrated framework," *International Journal of Physical Distribution & Logistics Management* 35(4):210-232.

Perrings C. 2006. "Resilience and sustainable development," *Environment & Development Economics* 11(4):417-427.

Pettit T, Fiksel J and Croxton K. 2010. "Ensuring supply chain resilience: Development of a conceptual framework," *Journal of Business Logistics*, 31(1):1-21.

Rice J and Caniato F. 2003. "Building a secure and resilient supply network," *Supply Chain Management Review* 7(5):22-30.

Rubin H and Rubin I. 2005. *Qualitative interviewing: The art of hearing data* 2nd ed. Thousand Oaks, CA: Sage Publications.

Sheffi Y. 2005. *The resilient enterprise: Overcoming vulnerability for competitive advantage*, Cambridge, MA: MIT Press.

Sheffi Y. 2008. "Logistics transformation and the resilient enterprise," Keynote address, 43rd Annual International Logistics Conference and Exhibition, International Society for Logistics SOLE. Orlando, FL, August 19, 2008.

Sheffi Y and Rice J. 2005. "A supply chain view of the resilient enterprise," *MIT Sloan Management Review* 47(1):41-48.

Slone R, Mentzer J and Dittmann J. 2007. "Are you the weakest link in your company's supply chain?", *Harvard Business Review* 85(9):116-127.

Snowden D and Boone M. 2007. "A leader's framework for decision making," *Harvard Business Review* 85(11):68-76.

Starr R, Newfrock J and Delurey M. 2003. "Enterprise resilience: managing risk in the networked economy," *strategy+business* 30(1):1-150, www.strategy-business.com (January 3, 2007).

Svensson G. 2000. "A conceptual framework for the analysis of vulnerability in supply chains," *International Journal of Physical Distribution & Logistics Management* 30(9):731-749.

Svensson G. 2002. "Dyadic vulnerability in companies' inbound and outbound logistics flows," *International Journal of Logistics and Research Applications* 5(1):13-44.

Svensson G. 2004. "Vulnerability in business relationships: The gap between dependence and trust," *Journal of Business and Industrial Marketing* 19(7):469-483.

Tang C. 2006a. "Perspectives in supply chain risk management," *International Journal of Production Economics* 103(2):451-488.

Tang C. 2006b. "Robust strategies for mitigating supply chain disruptions," *International Journal of Logistics: Research and Applications* 9(1):33–45.

Takahashi Y. 2011. "Japan auto demand to fall on earthquake woes," *Wall Street Journal Online*, www.wsjonline.com, September 28, 2011 (December 8, 2011).

Towers-Perrin 2006. "A changing risk landscape: A study of corporate ERM in the U.S.," November 2006, www.towersperrin.com (July 25, 2008).

Voss C, Tsikriktsis N and Mark F. 2002. "Case research in operations management," *International Journal of Physical Distribution and Logistics Management* 22(5):3-14.

Wisdomnet. 2006. "Managing supply chain risk: Building in resilience and preparing for disruption," www.wisdomnet.net (December 10, 2006).

Yin R. 2003. *Case study research: Design and methods* 3rd ed. Thousand Oaks, CA: Sage Publications, Inc.

Zsidisin G. 2003. "A grounded definition of supply risk," *Journal of Purchasing and Supply Management* 9(5/6):217-224.

APPENDIX

Focus Group Protocol

Part I: Introductions and Demographics

Part II: Evaluation of a Disruption – Identification, Mitigation, and Adaptation

1. Before the disruption
    a. When was the disruption first identified?
    b. How did it actually begin?
    c. Did you have any warning?
    d. How was the disruption first identified?
    e. Who were the first to identify the problem? Who else was affected?
2. Severity and frequency of the impact of the disruption
    a. What was the immediate impact of the disruption?
    b. When, if at all, did your customers notice any negative impacts? How?
    c. Are your customers the end consumer?
    d. Does this type of event happen often?
3. During the disruption
    a. What was the initial response to the disruption?
    b. Was this completely successful?
    c. Did any of your actions make the problem worse?
    d. Was your primary concern the length of time that the disruption would last or the severity of the disruption (i.e., minimize impact of longer period, or short but painful)?
    e. Were you able to quantify the total impact of the disruption?
        i. Financial?
        ii. Performance?
        iii. Customer service/satisfaction?
    f. Once the initial disruption was resolved, were there any longer-term impacts? Were there any changes that were made?
4. Causes
    a. Did you attempt to analyze the root cause of this disruption?
    b. How was this cause related to:
        i. Characteristics of your product?
        ii. Aspects of your production process?
        iii. Factors of your distribution network?

5. Learning from the disruption
    a. What did your company learn from this disruption?
    b. How did the firm change following this disruption (policy, structure, etc.)?
    c. How long did it take to implement these changes?
    d. Have these changes become 'permanent' or have procedures reverted to previous methods?

Part III: Redesigning the Supply Chain

1. Internal Processes
    a. Preparation:
        1. What are the methods that you use to prepare for potential disruptions?
        2. What types of security do you employ to protect against threats? (natural disasters, stock-outs, deliberate threats)
        3. Anticipation: How do you anticipate disruptions?
    b. Response
        1. What are the first steps that taken when a disruption is discovered?
        2. What are key roles that you play during recovery operations?
        3. Do you inform your customers of current or projected disruptions?
        4. Is your customer is the end consumer?
        5. How do you use the media during crises?
        6. Are your preparedness plans used during recovery?
2. Suppliers
    a. How can your suppliers help you to be prepared for a disruption?
    b. How can your suppliers help you respond to an event?
    c. Do your suppliers provide any insight on future events or trends?
3. Customers
    a. How can your customers help you to be prepared for a disruption?
    b. How can your customers help you respond to an event?
    c. Do your customers provide any insight on future events or trends?
4. Distributors: How can your distributors help you respond to an event?
5. Others: Who else can assist you in responding to an event?
6. Learning
    a. Following a disruption, do you discuss the event and create an after-actions report?
    b. What are some key aspects of an "After Actions report"?
    c. Are the lessons learned communicated to the entire workforce? How?
    d. What types of issues can impede implementation of improvements?
7. Using positive change to create opportunities
    a. How do you anticipate positive change?
    b. What are some ways that you create positive change?

Table A1: Turbulence Linkages

Vulnerability Factor	Sub-factor	Linked Capability Factors
Turbulence (V1)	Unpredictability in customer demand (V1.1)	• Commonality (C1.1) * • Product modularity (C1.2) ** • Multiple pathways (C1.3) * • Supply contract flexibility (C1.4) * • Alternate suppliers (C1.5) * • Logistics multi-sourcing (C2.1) * • Postponement (C2.2) * • Demand pooling (C2.3) ** • Inventory management (C2.4) ** • Reserve capacity (C3.3) * • Labor productivity (C4.1) * • Asset utilization (C4.2) * • Information technology (C5.1) * • Asset visibility (C5.2) * • Information exchange (C5.3) * • Business intelligence (C5.4) * • Strategic gaming and simulation (C6.2) * • Seizing advantage (C6.3) * • Lead-time reduction (C6.5) * • Learning from experience (C6.6)* • Demand forecasting (C7.1) * • Risk identification and prioritization (C7.2) * • Recognition of early warning signals (C7.4) * • Contingency planning and exercising (C7.5) * • Recognition of opportunities (C7.6) * • Resource mobilization (C8.1) * • Consequence mitigation (C8.4) * • Dispersion of markets (C9.5) * • Collaborative forecasting (C10.1) * • Collaborative information sharing (C10.2) * • Postponement of orders (C10.3) ** • Product life cycle management (C10.4) ** • Risk sharing (C10.5) * • Creative problem solving (C11.1) * • Accountability (C11.2) * • Benchmarking (C11.5) * • Market share (C12.3) * • Customer relationships (C12.5) * • Customer communications (C12.6) * • Price margin (C14.4) *

* Significant from a two-way comparison only (A-B, B-C and/or A-C).
** Three-way comparison results.

Continued

Table A1 continued

Vulnerability Factor	Sub-factor	Linked Capability Factors
Turbulence (V1)	Fluctuations in currencies and prices (V1.2)	• Consequence mitigation (C8.4) * • Price margin (C14.4) *
	Exposure to geopolitical disruptions (V1.3)	• Alternate distribution channels (C2.5)* • Business intelligence (C5.4) * • Seizing advantage (C6.3) * • Learning from experience (C6.6)* • Recognition of early warning signals (C7.4) * • Communications strategy (C8.2) * • Consequence mitigation (C8.4) ** • Risk sharing (C10.5) ** • Substitute leadership (C11.4) * • Financial reserves (C14.1) * • Portfolio diversification (C14.2) *
	Exposure to natural disasters (V1.4)	• Demand pooling (C2.3) * • Back-up utilities (C3.1) * • Asset visibility (C5.2) * • Recognition of early warning signals (C7.4) * • Recognition of opportunities (C7.6) * • Resource mobilization (C8.1) * • Crises management (C8.3) * • Caring for employees (C11.6) *
	Unforeseen technology failures (V1.5)	• Lead-time reduction (C6.5) * • Demand forecasting (C7.1) * • Consequence mitigation (C8.4) *
	Pandemic (V1.6)	• Empowerment (C9.4) * • Dispersion of markets (C9.5) *

* Significant from a two-way comparison only (A-B, B-C and/or A-C).
** Three-way comparison results.

Table A2: Deliberate Threats Linkages

Vulnerability Factor	Sub-factor	Linked Capability Factors
Deliberate threats (V2)	Terrorism and sabotage (V2.1)	• Alternate sources (C1.5) * • Redundant assets (C3.2) * • Recognition of early warning signals (C7.4) *
	Piracy and theft (V2.2)	• Asset visibility (C5.2) * • Lead-time reduction (C6.5) * • Learning from experience (C6.6)* • Consequence mitigation (C8.4) * • Decentralization of resources (C9.1) * • Layered defenses (C13.1) * • Access restriction (C13.2) * • Insurance coverage (C14.3) *
	Union activities (V2.3)	• Reserve capacity (C3.3) * • Re-routing requirements (C6.1) * • Learning from experience (C6.6) * • Contingency planning (C7.5) * • Communications strategy (C8.2) * • Crisis management (C8.3) ** • Consequence mitigation (C8.4) * • Risk sharing (C10.5) * • Market share (C12.3) *
	Special interest groups (V2.4)	• Lead-time reduction (C6.5) *
	Industrial espionage (V2.5)	• Back-up utilities (C3.1) * • Redundant assets (C3.2) * • Risk identification and prioritization (C7.2) * • Monitoring normal deviations (C7.3) * • Collaborative information sharing (C10.2) * • Brand equity (C12.1) * • Layered defenses (C13.1) * • Access restriction (C13.2) * • Employee involvement in security (C13.3) * • Collaboration with governments (C13.4) * • Cyber-security (C13.5) * • Personnel security (C13.6) * • Portfolio diversification (C14.2) *
	Product liability (V2.6)	• *No specific linkages*

* Significant from a two-way comparison only (A-B, B-C and/or A-C).
** Three-way comparison results.